

- [54] METHOD AND APPARATUS FOR QUADRATURE MODULATION
- [75] Inventor: Clifford D. Leitch, Coral Springs, Fla.
- [73] Assignee: Motorola, Inc., Schaumburg, Ill.
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- [22] Filed: Jan. 11, 1988
- [51] Int. Cl.⁴ H03C 1/00
- [52] U.S. Cl. 332/41; 332/48; 375/39
- [58] Field of Search 332/31 R, 41, 42, 48; 455/59, 60, 95, 108; 375/39

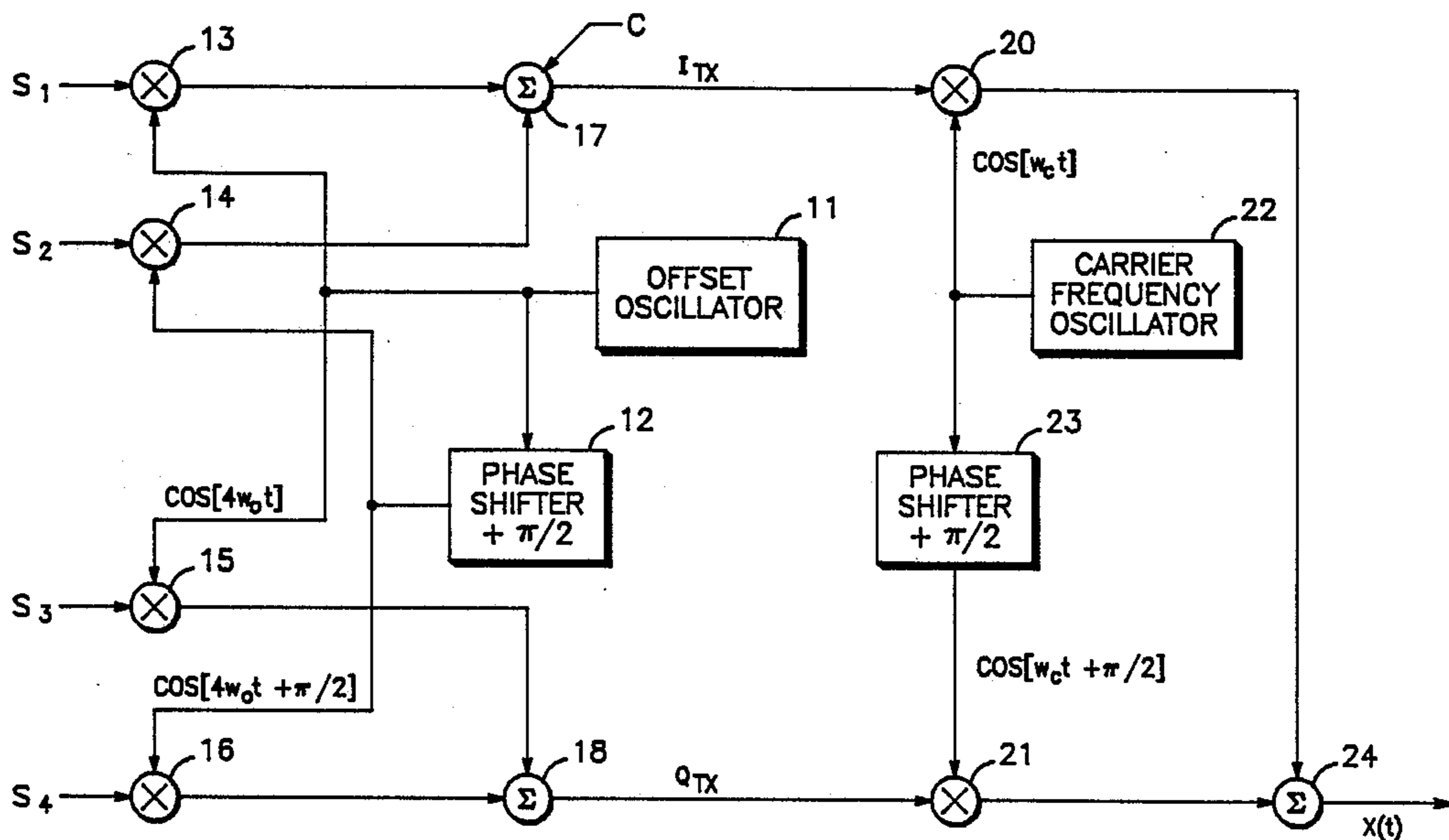
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Primary Examiner—Eugene R. LaRoche
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[57] ABSTRACT
 A quadrature amplitude modulation system utilizes two subcarrier signals, each quadrature modulated with information signals which are quadrature modulated onto the RF carrier. This provides a hole in the center of frequency spectrum, permitting carrier and bit sync signals can be provided in the center area of the signal spectrum.

11 Claims, 6 Drawing Sheets



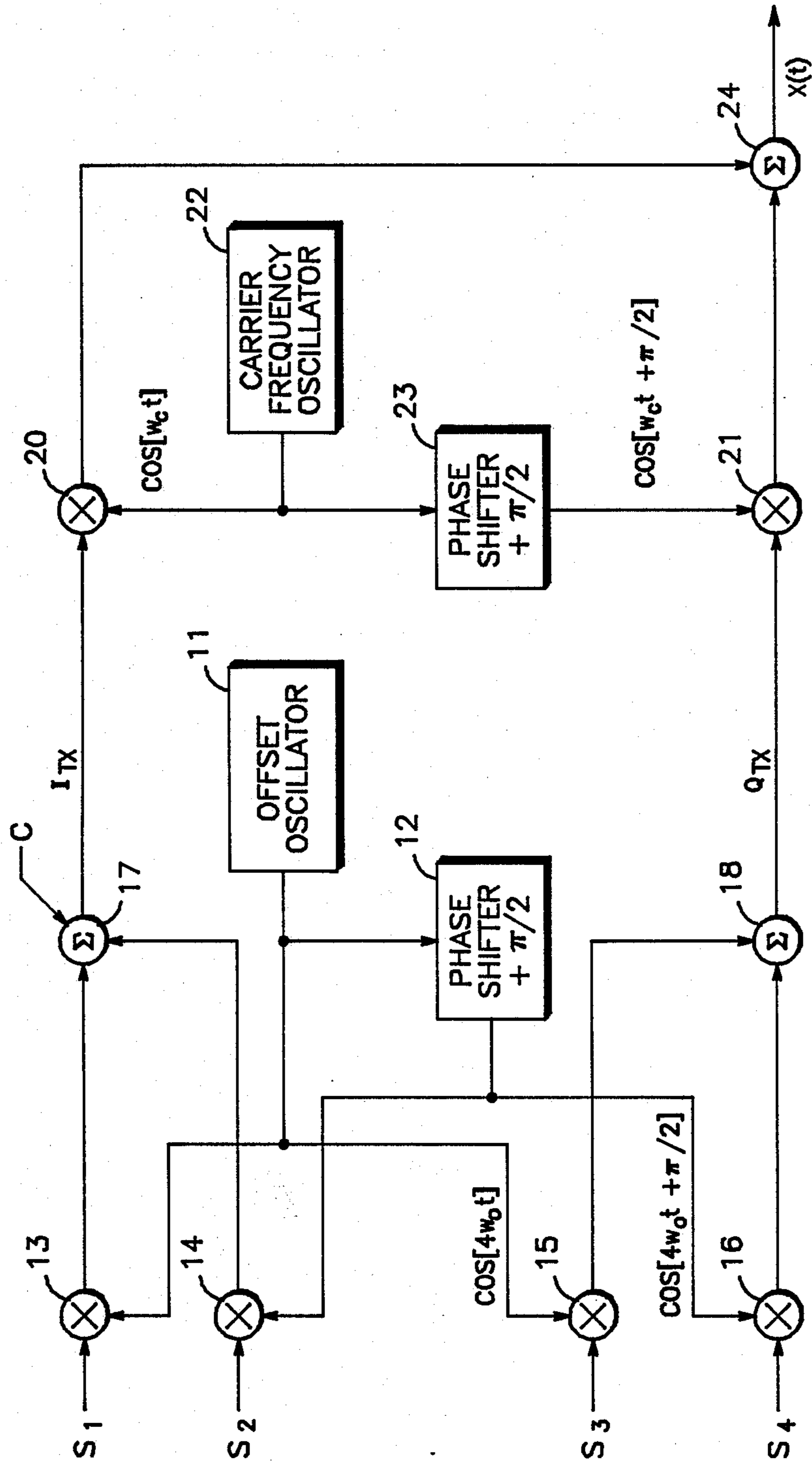


FIG. 1

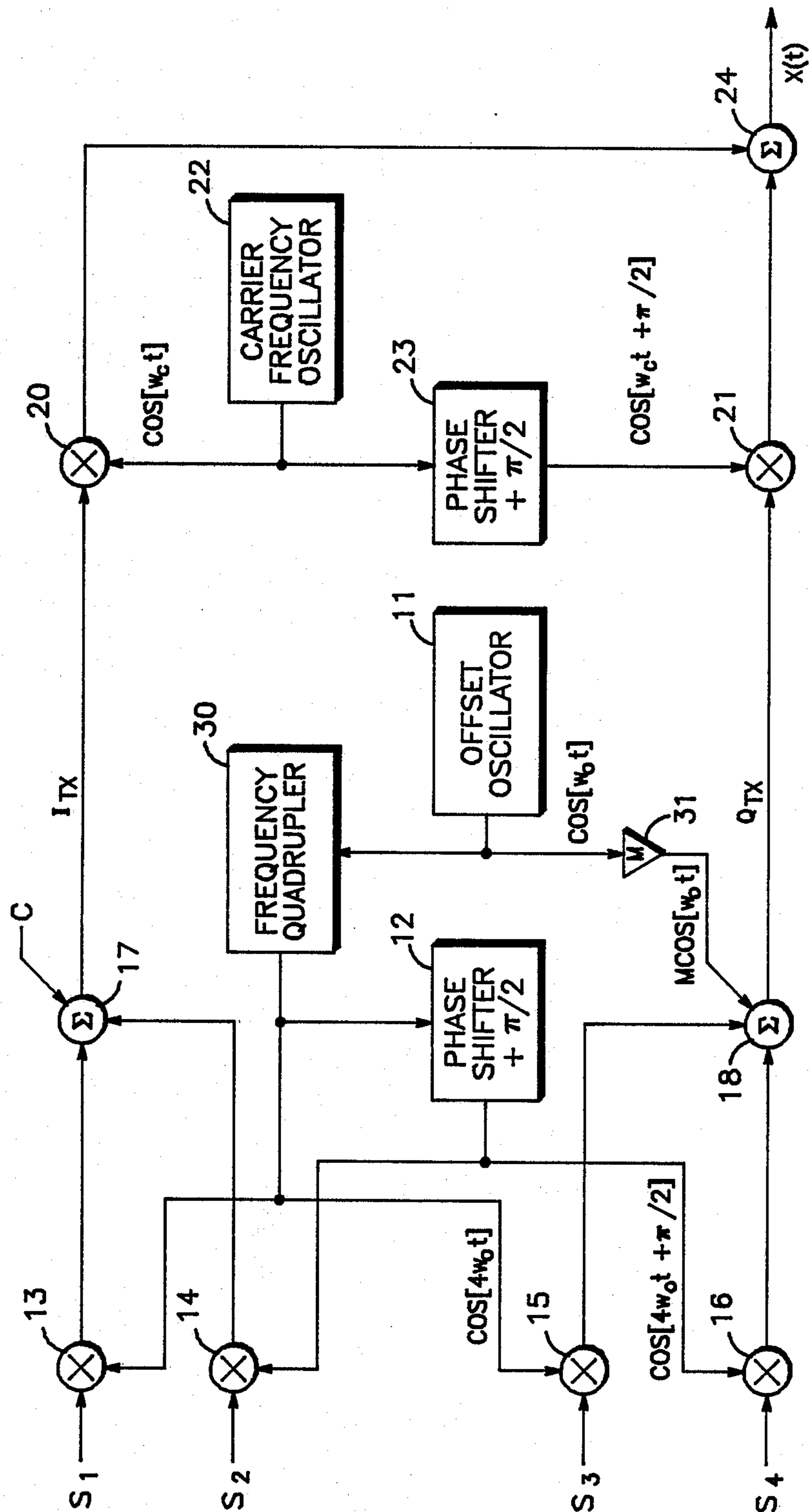
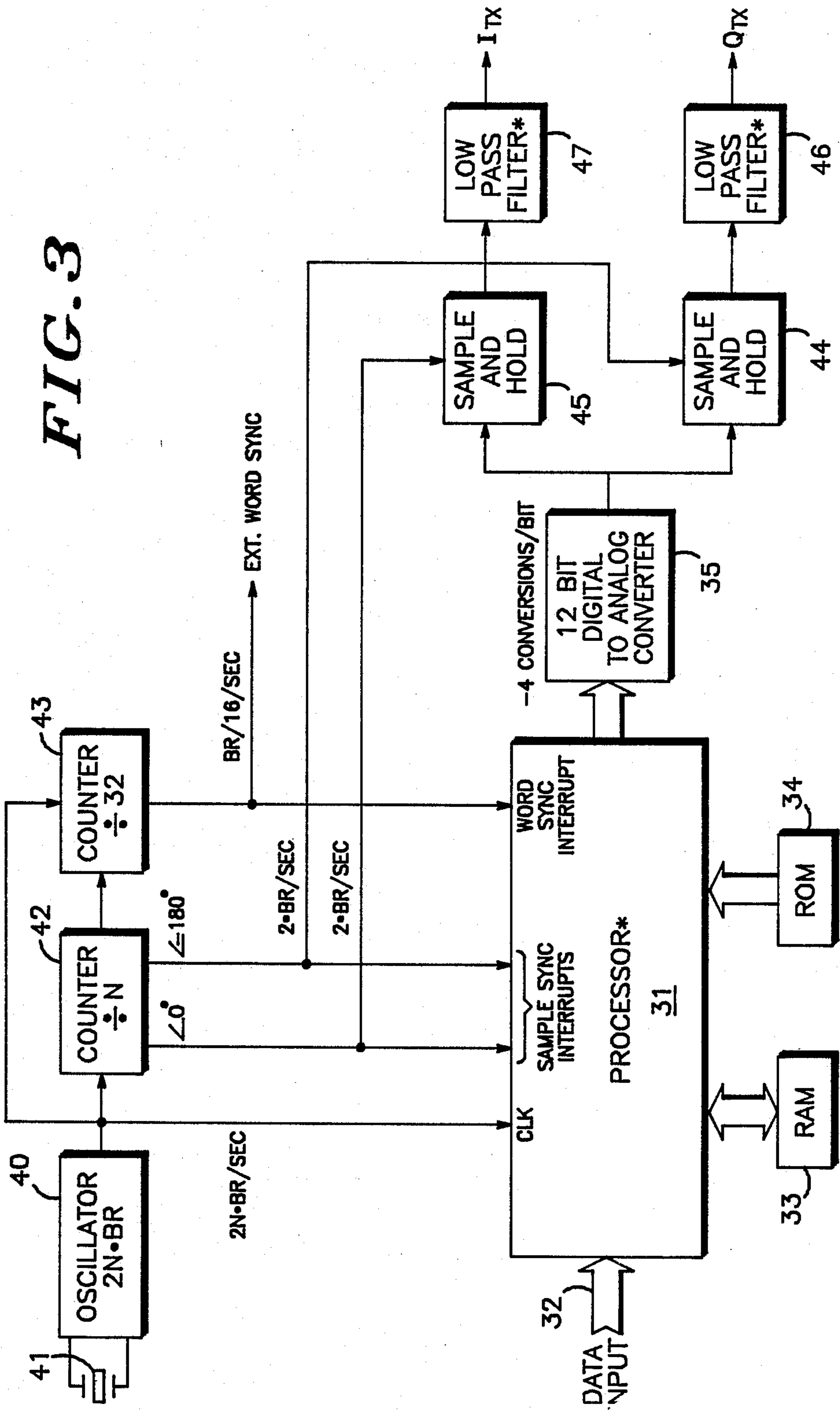


FIG. 2

FIG. 3



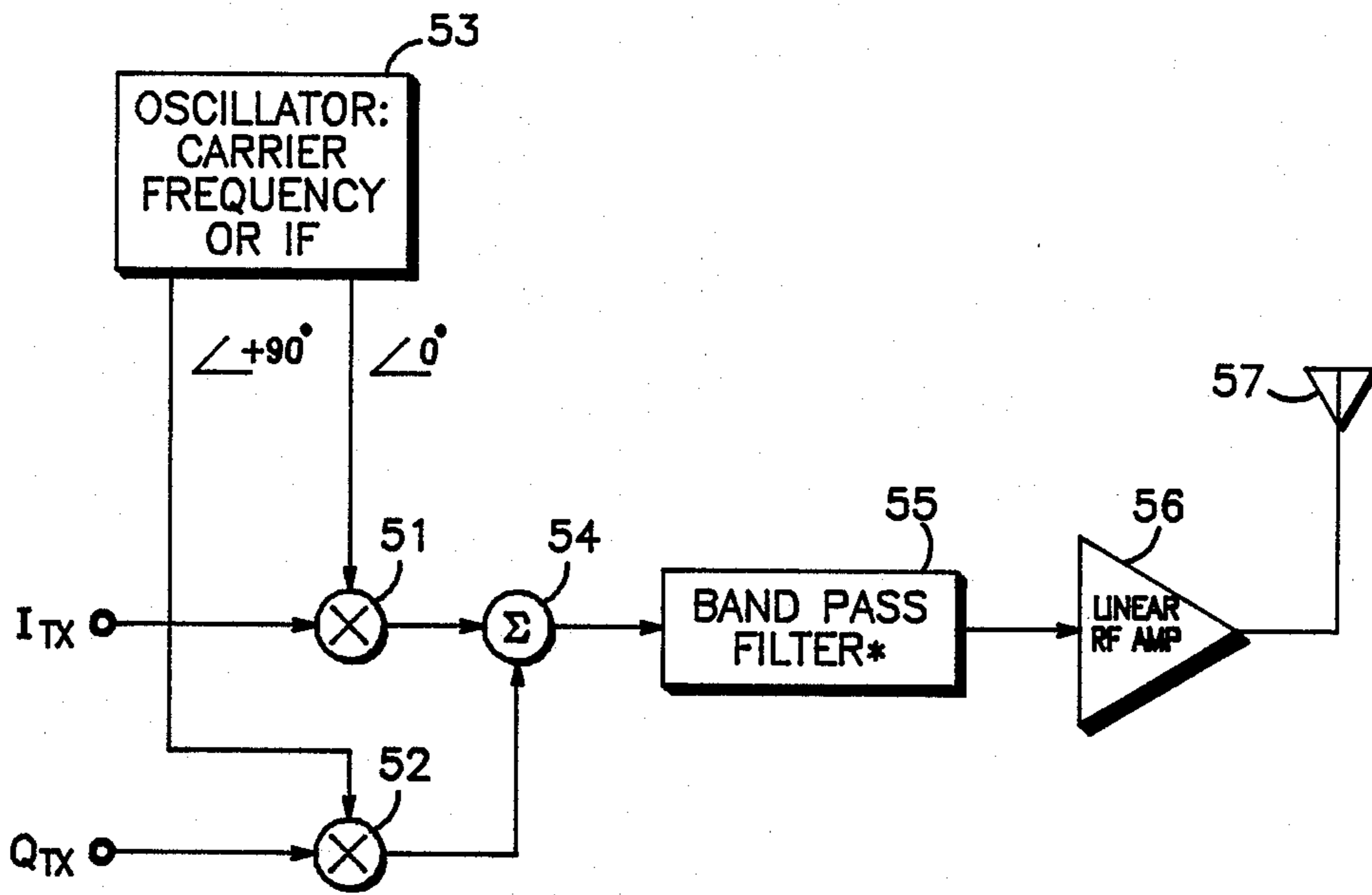


FIG. 4

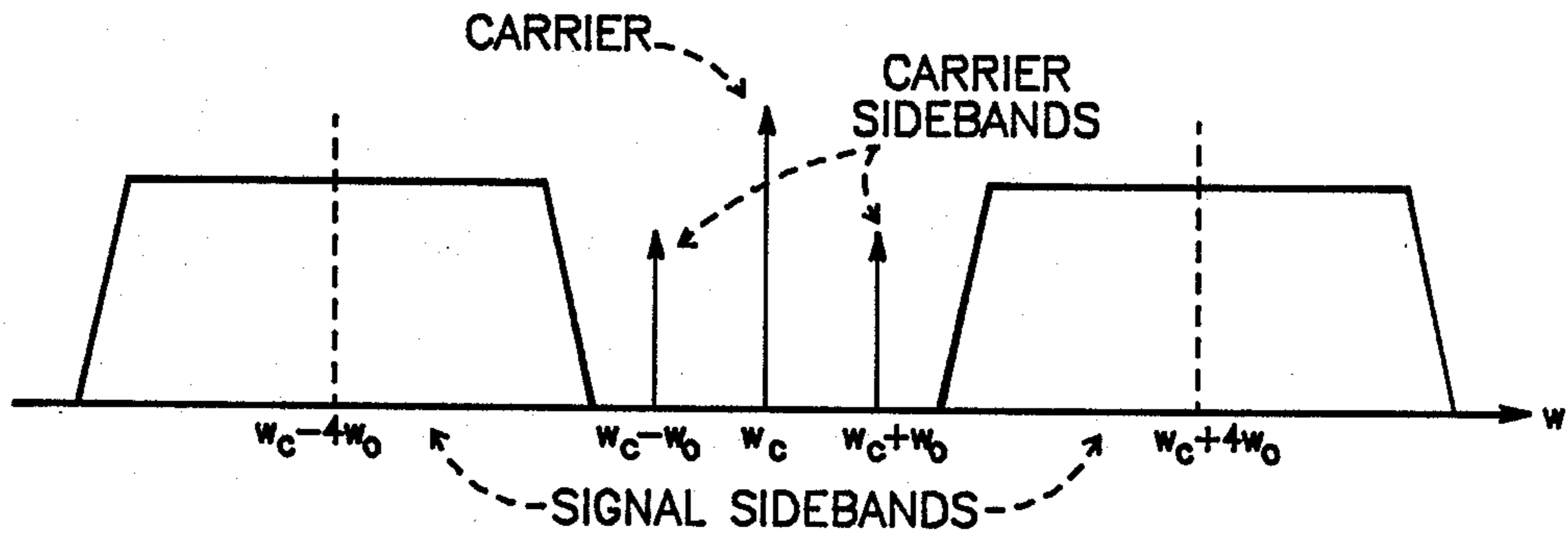
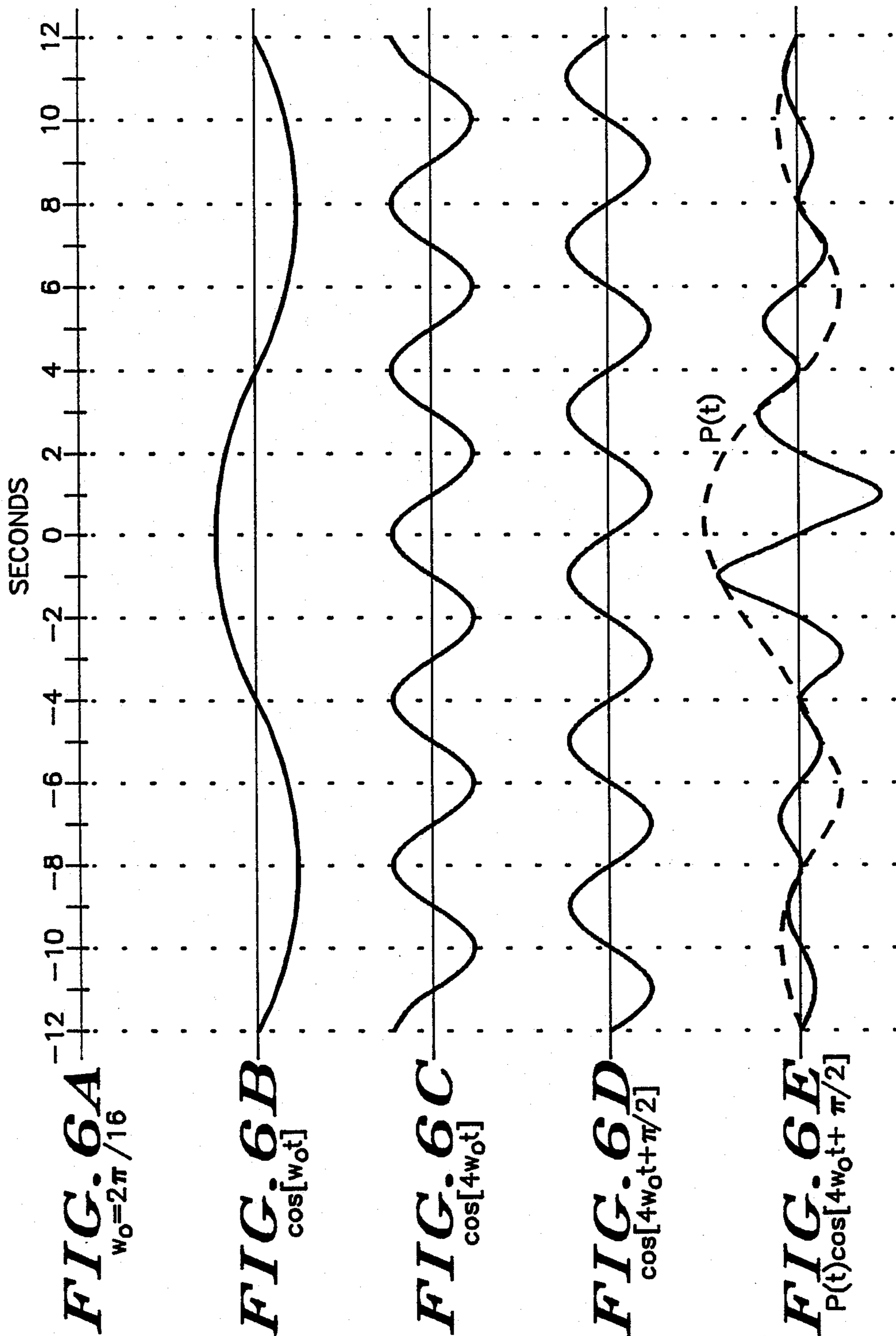
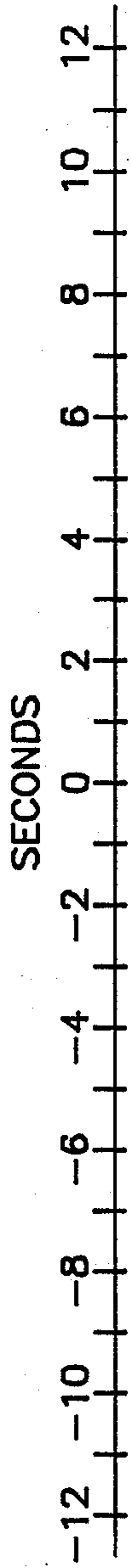


FIG. 5





$P(t-1)$

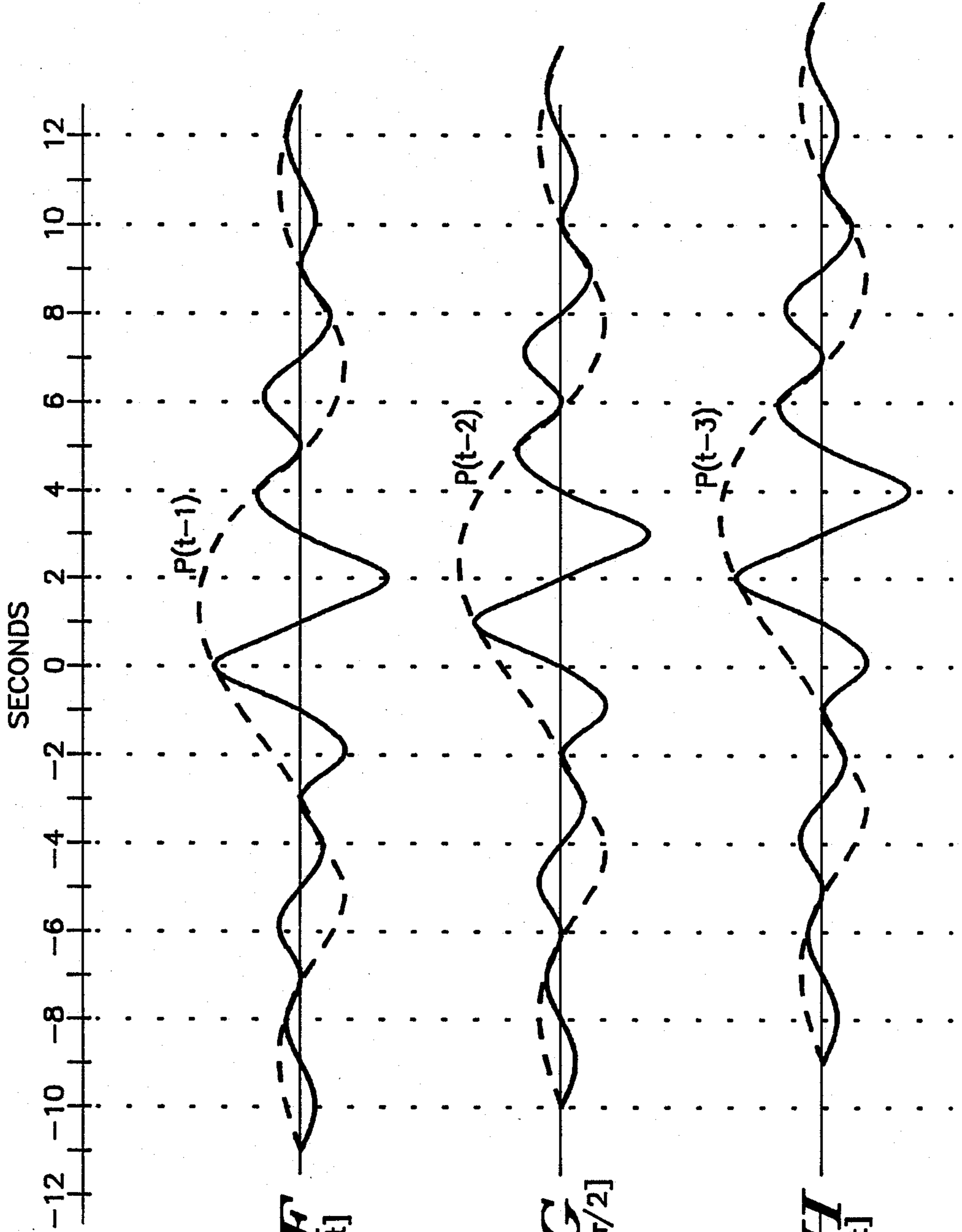
FIG. 6F
 $P(t-1)\cos[4\omega_0 t]$

$P(t-2)$

FIG. 6G
 $P(t-2)\cos[4\omega_0 t + \pi/2]$

$P(t-3)$

FIG. 6H
 $P(t-3)\cos[4\omega_0 t]$



METHOD AND APPARATUS FOR QUADRATURE MODULATION

BACKGROUND OF THE INVENTION

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This invention relates to quadrature amplitude modulation systems in general and particularly to a system in which signal components are modulated onto a subcarrier to allow for inclusion of carrier and bit sync information at the center of the transmitted frequency spectrum. In a quadrature modulation system, designed for radio transmission, it is desirable to transmit a pilot carrier in order to facilitate reception and decoding of the transmitted information. While it is known to transmit a pilot carrier, such carriers have been added as a side frequency to the quadrature amplitude modulated signal. There are, however, limitations and disadvantages to this approach. Due to selective fading, such as can occur on a radio path, problems can result where the pilot carrier is spaced from the signal information. Additionally, problems can occur due to limitations in the passband of receivers in that the pilot carrier signal may fall too close to or outside of receiver's passband filter edge. Consequently, it is desirable that such a pilot carrier be located more centrally to the transmitted frequency spectrum.

Where digital information is to be transmitted in a synchronous manner, channel fading and noise can prevent the maintenance of bit sync. In such a system it is therefore desirable to transmit a bit sync signal with the synchronous digital information. Like the pilot carrier, the bit sync signal should be provided as close to the center of the transmitted frequency spectrum as possible.

SUMMARY OF THE INVENTION

This method and apparatus for a quadrature amplitude modulation permits the inclusion of both the carrier pilot and bit sync signals at and adjacent to the center of the signal spectrum.

A method of transmitting a quadrature amplitude modulated signal including the steps of: quadrature modulating first and second signals onto a subcarrier; quadrature modulating third and fourth signals onto a subcarrier; quadrature modulating the first and second quadrature modulated subcarriers onto a carrier; and transmitting the quadrature modulated carrier.

In one aspect of the invention, the method includes the further step of providing a DC component with one of the quadrature modulated subcarrier to produce a pilot carrier. In another aspect of the invention, the method includes the further step of providing a bit sync signal with one of said quadrature modulated subcarriers. In still another aspect of the invention, the signals are digital signals having a predetermined bit rate and the bit sync signal has a frequency that is an integral submultiple of the bit rate.

In still another aspect of the invention, a method of transmitting a quadrature amplitude modulated signal includes the steps of reading from memory first and second prototype pulses each including a subcarrier

component, summing the first and second prototype pulses to produce a first quadrature modulated subcarrier, reading from memory third and fourth prototype pulses each including a subcarrier component, summing said third and fourth prototype pulses to produce a second quadrature modulated subcarrier, quadrature modulating a carrier with said first and second quadrature modulated subcarriers and transmitting the quadrature modulated carrier.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a quadrature amplitude modulation system in accordance with the present invention, particularly suitable for the transmission of analog signals.

FIG. 2 is a block diagram of another quadrature amplitude modulation system in accordance with the present invention, particularly suitable for the transmission of digital signals.

FIG. 3 is a schematic block diagram of another quadrature amplitude modulation system in accordance with the present invention, which utilizes predetermined pulse waveforms.

FIG. 4 is a schematic block diagram of a transmitter backend for use with the system of FIG. 3.

FIG. 5 is a graphical representation of the frequency spectrum of a quadrature modulated signal with a pilot carrier and bit sync signals in accordance with the present invention.

FIG. 6A is a time line normalized for 1 bit per second.

FIG. 6B is a graphical representation of the offset oscillator output $\cos(\omega_0 t)$.

FIG. 6C is a graphical representation of the frequency quadrupler output or subcarrier $\cos(4\omega_0 t)$.

FIG. 6D is a graphical representation of the phase shifter output or quadrature subcarrier $\cos(4\omega_0 t + \pi/2)$.

FIG. 6E is a graphical representation of the S2 channel pulse $P(t)$ modulated on the quadrature subcarrier of FIG. 6D.

FIG. 6F is a graphical representation of the S1 channel pulse $P(t-1)$ modulated on the subcarrier of FIG. 6C.

FIG. 6G is a graphical representation of the S4 channel pulse $P(t-2)$ modulated on the quadrature subcarrier of FIG. 6D.

FIG. 6H is a graphical representation of the S3 channel pulse $P(t-3)$ modulated on the subcarrier of FIG. 6C.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now by characters of reference to the drawings and first to FIG. 1, a quadrature modulation system is shown which is capable of providing a pilot carrier signal in the center of the signal spectrum. Four input signals S1-S4 which can be independent analog and/or digital signals are combined. This particular system is most suitable for analog signals as no provision is made for insertion of bit sync information.

An offset oscillator 11 is used to provide a subcarrier signal $\cos[\omega_0 t]$. Its output is also provided to a 90 degree phase shifter 12 which provides a quadrature subcarrier signal $\cos(\omega_0 t + \pi/2)$. The four input signals S1-S4 are applied to mixer or multiplier circuits 13-16 respectively. The subcarrier signal from oscillator 11 is applied to mixers 13 and 15 while the quadrature sub-

carrier signals, from phase shifter 12 is applied to mixers 14 and 16. The outputs of mixers 13 and 14 are combined at summer 17, while the outputs of mixer 15 and 16 are combined at summer 18. The output of summer 17 is the I_{tx} or in-phase signal for modulation on the RF carrier and the output of summer 18 is the Q_{tx} or quadrature signal for quadrature modulation on the RF carrier. Mixers 13 and 14 and summer 17 constitute means for quadrature modulating first and second signals on a first subcarrier while mixers 15 and 16 and summer 18 constitute means for quadrature modulating third and fourth signals on a second subcarrier.

When it is desired to provide a pilot carrier signal for transmission with the quadrature modulated signals, a DC offset voltage, having a magnitude C , is applied to one of the summers 17 and 18. In this embodiment, DC voltage is applied to the summer 17. The outputs of summers 17 or 18 are provided to mixer or multipliers 20 and 21 respectively. A carrier frequency oscillator 22 provides an in phase carrier signal $\cos(\omega_c t)$ which is applied to the mixer 20 and to the input of a 90 degree phase shifter 23. The output of phase shifter 23, which is the quadrature carrier signal $\cos(\omega_c t + \pi/2)$, is applied to the mixer 21. The outputs of mixers 20 and 21 are provided to a summing circuit 24 to produce the combined transmit signal $X(t)$. The $X(t)$ signal can then be applied as through a bandpass filter and amplifier to an antenna, which constitute means for transmitting the quadrature modulated carrier, for radio transmission as is discussed subsequently in regard to FIG. 4. The mixers 20 and 21 and summer 24 constitute means for quadrature modulating the subcarriers onto a carrier.

When digital signals are to be transmitted, it is desirable to provide a bit sync signal. The bit sync signal can be provided as sideband signals to the carrier signal and be located in the frequency spectrum between the quadrature signals. A system suitable for digital communication is illustrated in FIG. 2. The parts of FIG. 2 which are identical to the parts of FIG. 1 are indicated with the same reference numeral. The principal difference involves the offset oscillator arrangement. In this case, the offset oscillator 11 provides an output frequency ω_0 which is one quarter of the oscillator frequency of FIG. 1. The frequency ω_0 is chosen as an integer submultiple of the bit rate and in the preferred embodiment is one-fourth of the bit rate of each of the subchannels (one-sixteenth of the total bit rate). The output of offset oscillator 11 of FIG. 2 is applied to a frequency quadrupler 30 for application to the phase shifter 12 and mixers 13, 14, 15 and 16 in a manner identical to FIG. 1. However, the lower frequency signal of offset oscillator 11 is also applied to an amplifier 31 having an amplification factor equal to M . Its output is applied, in this case, to the summer 18 constituting means for summing a sync signal with one of the subcarriers. It will be understood that the output of amplifier 31 could be applied to the summer 17 and the carrier signal C applied to the summer 18 if desired or both to the same summer. The I_{tx} and Q_{tx} signals are then quadrature modulated on the carrier frequency as in FIG. 1. The output signal $X(t)$ includes not only the quadrature modulated signal components but also a carrier and bit sync sidebands as illustrated in FIG. 5. The S1-S4 signals are preferably predetermined pulses $P(t)$ read from a memory ROM, such as it is disclosed in co-pending U.S. Pat. No. 4,737,969, issued Apr. 12, 1988, and owned by the assignee of this invention, the disclosure of which is incorporated by reference as if fully set out herein.

When using stored pulses, the mixing or multiplication step of mixers 13-16 can be eliminated by reading from memory pulses representative of the product of the multiplication or mixing, provided the bit rate and subcarrier frequency are related by an integer ratio.

FIG. 3 illustrates a microprocessor based system for providing the I_{tx} and Q_{tx} signals. In this case a digital signal processor 31, constituting processor means, includes a data input 32 for receiving the digital data to be transmitted. The digital data can be four independent digital data stream or preferably a single data stream can be subdivided as the S1-S4 signals. The processor 31 includes RAM 33 and ROM 34. The ROM 34 includes the preprogrammed waveforms which are summed to provide the I_{tx} and Q_{tx} signals. The I_{tx} signal is produced by adding an S1 stored pulse corresponding to $P(t-1) \cos(4\omega_0 t)$ of FIG. 6F to an S2 signal corresponding to $P(t) \cos(4\omega_0 t + \pi/2)$ of FIG. 6E along with the carrier amplitude constant C . Similarly for the Q_{tx} signal, the S3 signal $P(t-3) \cos(4\omega_0 t)$ and the S4 stored pulse $P(t) \cos(4\omega_0 t + \pi/2)$ of FIG. 6G are added along with the bit sync signal $M \cos(4\omega_0 t)$. The process continues similarly for each successive set of 4 bits. It will be appreciated that for a binary system it is only necessary to store one prototype pulse. It is negated to represent the other binary signal. Also as illustrated in FIGS. 6E-6H, the same waveform is used on each channel S1-S4 differing only in phase or time. While the preferred embodiment utilizes binary or two level signals, multilevel (e.g. 8 level) signals could be provided on each channel to increase information throughput. It would then be necessary to store four pulses for an 8 level signal since their negatives would represent the other four levels which can be easily computed by the processor 31.

The output of processor 31 is applied to a 12 bit D/A converter 35. An oscillator circuit 40, having a crystal, 41 provides an output frequency equal to $2N \times \text{Bit Rate}$ which is applied to the clock input of processor 31 and the clock inputs of counters 42 and 43. Counter 42, constituting a divide by N counter, provides 0 degree and a -180 degree outputs, which are applied to the processor 31 as a sample sync interrupts and are also applied to sample and hold circuits 44 and 45, respectively. These are at twice the bit rate to permit the single D/A converter 35 to be used for both the I_{tx} and Q_{tx} signals. The inputs of sample and hold circuits 44 and 45 are connected to the output of the D/A converter 35. Low pass filters 46 and 47 are connected to the outputs of the sample and hold circuits 44 and 45 with their outputs providing the Q_{tx} and I_{tx} transmit signals. These are then quadrature modulated on the carrier frequency ω_c as in FIG. 1 and 2. In this embodiment, a Texas Instruments TMS 32020 Digital Signal Processor can be utilized. The object code including the prototype pulse information as stored in ROM 34 is given in Table 1, which is appended hereto.

Referring now to FIG. 4, the radio backend for quadrature modulation of the I_{tx} and Q_{tx} signals of FIG. 3 onto a carrier, is illustrated. The I_{tx} and Q_{tx} signals are applied to mixers 51 and 52 respectively which correspond to the mixers 20 and 21 of FIGS. 1 and 2. The carrier and 90 degrees quadrature carrier signals are provided to mixers 51 and 52 respectively, as by carrier frequency oscillator 53 which corresponds to the carrier frequency oscillator 22 and phase shifter 23. The output of mixers 51 and 52 are applied to a summer 54 whose output provides the transmit signal $X(t)$.

The backend of the transmitter is identical to that to be used in the circuits of FIG. 1 and FIG. 2. The output of the summer 54 in this case, or the summer 24 of FIGS. 1 and 2, is applied to a bandpass filter 55 having its output applied to a linear RF amplifier 56, the output of which is transmitted via antenna 57. The transmitted signal includes the input signals modulated on subcarriers, the center carrier signal and the two carrier sideband bit sync signals as illustrated in FIG. 5. The carrier and bit sync signals are useful when demodulating the received transmitted signal in order to compensate for selective fading that can occur over a radio path.

In operation, a first pair of signals are quadrature

modulated onto a first subcarrier while a second pair of signals are quadrature modulated onto a second subcarrier. The two quadrature modulated subcarriers are then quadrature modulated onto the carrier resulting in the information carrying components signal being spaced from the carrier frequency. A pilot carrier signal and bit sync signals can be inserted between sidebands carrying the twice quadrature modulated information signals. This provides a spectrally efficient signal capable of being successfully transmitted over an unstable channel. Consequently, it can be used in applications, such as land mobile radio where conventional quadrature amplitude modulation cannot be reliably applied.

TABLE 1

K0000XMT 11.590000BFF80B0020BFF80B0599BFF80B059990020BCE02BCE077F187F	XMT 11.1
BC800BCE08B5589BC103BD001BFFFFB60A0BD001BFFC1B60A0BCA00B68B0BC8067F0E7F	XMT 11.2
BCA01B604EB604F8B050B9F50BF8B0B014BBD001B07CFB604CBD001B00C5B604D7F130F	XMT 11.3
B204EB104FB604EBF180B004FBCA19B604EBC104BD001BFFC2B6080BCE00BCE1F7F0F1F	XMT 11.4
BC104BD001BFFC2B6080BFF80B0051BCE00BCE1FBD001B065DB604CBD001B01EE7F101F	XMT 11.5
B604DBCE00BCE1FBD001B03EBB604CBD001B021BB604DBCE00BCE1FBD001B01357F10BF	XMT 11.6
B604CBD001B00FDB604DBCE00BCE1FBD001BFF03B604CBD001BFECBB604DBCE007F0C2F	XMT 11.7
BCE1FBD001BFDEBB604CBD001BFC15B604DBCE00BCE1FBD001BFE12B604CBD0017F0B9F	XMT 11.8
BF9A3B604DBCE00BCE1FBD001BFF3BB604CBD001BF831B604DBCE00BCE1FBD0017F0B3F	XMT 11.9
B00C5B604CBD001BF831B604DBCE00BCE1FBD001B01EEB604CBD001BF9A3B604D7F0FBF	XMT 11.10
BCE00BCE1FBD001B021BB604CBD001BFC15B604DBCE00BCE1FBD001B00FDB604C7F0E6F	XMT 11.11
BD001BFECBB604DBCE00BCE1FBD001BFECBB604CBD001B00FDB604DBCE00BCE1F7F07FF	XMT 11.12
BD001BFC15B604CBD001B021BB604DBCE00BCE1FBD001BF9A3B604CBD001B01EE7F104F	XMT 11.13
B604DBCE00BCE1FBD001BF831B604CBD001B00C5B604DBCE00BCE1FBD001BF8317F0EDF	XMT 11.14
B604CBD001BFF3BB604DBCE00BCE1FBD001BF9A3B604CBD001BFE12B604DBCE007F0C9F	XMT 11.15
BCE1FBD001BFC15B604CBD001BFDEBB604DBCE00BCE1FBD001BFECBB604CBD0017F097F	XMT 11.16
BFF03B604DBCE00BCE1FBD001B00FDB604CBD001B0135B604DBCE00BCE1FBD0017F0E7F	XMT 11.17
B021BB604CBD001B03EBB604DBCE00BCE1FBD001B01EEB604CBD001B065DB604D7F114F	XMT 11.18
BCE00BCE1FBD001B00C5B604CBD001B07CFB604DBCE00BCE1FBD001BFF3BB604C7F0C1F	XMT 11.19
BD001B07CFB604DBCE00BCE1FBD001BFE12B604CBD001B065DB604DBCE00BCE1F7F0CCF	XMT 11.20
BD001BFDEBB604CBD001B03EBB604DBCE00BCE1FBD001BFF03B604CBD001B01357F0F3F	XMT 11.21
B604DBCE00BCE1FBD001B0135B604CBD001BFF03B604DBCE00BCE1FBD001B03EB7F0E7F	XMT 11.22
B604CBD001BFDEBB604DBCE00BCE1FBD001B065DB604CBD001BFE12B604DBCE007F0D7F	XMT 11.23
BCE1FBD001B07CFB604CBD001BFF3BB604DBCE00BCE1BFF80B0036BD100B02007F0DFF	XMT 11.24
BC863BFCA0B059DBCE05BC806BD100B0300BCB1FBFCA0B0601B9E50BF9B0B01707F0F0F	XMT 11.25
BD100B0320BCB0ABFCA0B064DBD100B032BBCB0ABFCA0B0658BD100B0336BCB0A7F101F	XMT 11.26
BFCA0B0663BD100B0341BCB0ABFCA0B066EBFF80B01B4BD100B0320BCB0ABFCA07F0EDF	XMT 11.27
B0621BD100B032BBCB0ABFCA0B062CBD100B0336BCB0ABFCA07F0637BD100B03417F131F	XMT 11.28
BCB0ABFCA0B0642BCA00BA000BD100B0329BCB09B5D90BFF5ABD100B0334BCB097F0FCF	XMT 11.29
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BCB09B5D90BFF1EBCE15B0017B604DB204EB104FB604EBF180B01B4BCA19B604E7F0F1F	XMT 11.31
BC104BD001BFFC2B6080BCE00BCE1FBC104BD001BFFC2B6080BFF80B01B6BCE007F0DBF	XMT 11.32
BCE1FBFA00BA000BD100B0329BCB09B5D90BFF50BD100B0334BCB09B5D90BFF3C7F0E6F	XMT 11.33
BCE15B604CBCA00BA000BD100B033FBCB09B5D90BFF28BD100B034ABC09B5D907F0FBF	XMT 11.34
BFF14BCE15B0018B604DBCE00BCE1FBFA00BA000BD100B0329BCB09B5D90BFF467F0E4F	XMT 11.35
BD100B0334BCB09B5D90BFF32BCE15B604CBCA00BA000BD100B033FBCB09B5D907F10EF	XMT 11.36
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B604DB203AB6036B2045B6041BCE00BCE1FBFA00BA000BD100B0329BCB09B5D907F147F	XMT 11.40
BFF32BD100B0334BCB09B5D90BFF1EBCE15B604CBCA00BA000BD100B033FBCB097F0EEF	XMT 11.41
B5D90BFF5ABD100B034ABC09B5D90BFF46BCE15B0018B604DBCE00BCE1FBFA007F0AEF	XMT 11.42
BA000BD100B0329BCB09B5D90BFF28BD100B0334BCB09B5D90BFF14BCE15B604C7F10AF	XMT 11.43
BCA00BA000BD100B033FBCB09B5D90BFF50BD100B034ABC09B5D90BFF3CBCE157F0DBF	XMT 11.44
B001CB604DBCE00BCE1FBFA00BA000BD100B0329BCB09B5D90BFF1EBD100B03347F10DF	XMT 11.45
BCB09B5D90BFF0ABCE15B604CBCA00BA000BD100B033FBCB09B5D90BFF46BD1007F0D6F	XMT 11.46
B034ABC09B5D90BFF32BCE15B001DB604DBCE00BCE1FBFA00BA000BD100B03297F0F6F	XMT 11.47
BCB09B5C90BFF14BD100B0334BCB09B5C90BFF00BCE15B604CB2024B6020B202F7F120F	XMT 11.48
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B0334BCB09B5D90BFF46BCE15B604CBCA00BA000BD100B033FBCB09B5D90BFF327F0EDF	XMT 11.51
BD100B034ABC09B5D90BFF1EBCE15B001FB604DBCE00BCE1FBFA00BA000BD1007F0DCF	XMT 11.52
B0329BCB09B5D90BFF50BD100B0334BCB09B5D90BFF3CBCE15B604CBCA00BA0007F0EFF	XMT 11.53
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I claim as my invention:

1. A method of transmitting a quadrature amplitude modulated signal comprising the steps of:
 - quadrature modulating first and second signals onto a first subcarrier, quadrature modulating third and fourth signals onto a second subcarrier,
 - quadrature modulating said first and second quadrature modulated subcarriers onto a carrier, and transmitting said quadrature modulated carrier,
2. A method of transmitting a quadrature amplitude modulated signal comprising the steps of;
 - quadrature modulating first and second signals onto a first subcarrier
 - quadrature modulating third and fourth signals onto a second subcarrier,
 - providing a DC component with one of said quadrature modulated subcarriers for producing a pilot carrier,
 - quadrature modulating said quadrature first and second quadrature modulated subcarriers onto a carrier, and transmitting said quadrature modulated carrier.
3. A method of transmitting quadrature amplitude modulated signal as defined in claim 1, comprising the further step of providing a bit sync signal with one of said quadrature modulated subcarriers.
4. A method as defined in claim 3, in which the signals are digital signals having a predetermined bit rate and the bit sync signal has a frequency that is an integral multiple of said bit rate.
5. A method of transmitting a quadrature amplitude modulated signal, comprising:
 - reading from memory first and second prototype pulses each including a subcarrier component,
 - summing said first and second prototype pulses to produce a first quadrature modulated subcarrier,
 - reading from memory third and fourth prototype pulses each including a subcarrier component,
 - summing said third and fourth prototype pulses to produce a second quadrature modulated subcarrier,
 - quadrature modulating a carrier with said first and second quadrature modulated subcarriers, and transmitting said quadrature modulated carrier.
6. A method of transmitting a quadrature amplitude modulated signal comprising:
 - reading from memory first and second prototype pulses each including a subcarrier component,

- summing said first and second prototype pulses to produce a first quadrature modulated subcarrier,
 - reading from memory third and fourth prototype pulses each including a subcarrier component,
 - summing said third and fourth prototype pulses to produce a second quadrature modulated subcarrier,
 - quadrature modulating a carrier with said first and second quadrature modulated subcarriers,
 - summing an offset with one of said summed pulses prior to quadrature modulating said carrier, and transmitting said quadrature modulated carrier,
7. A method of transmitting a quadrature amplitude modulated signals defined in claim 5 including the further step of summing a sync signal with one of said summed pulses prior to quadrature modulating said carrier.
 8. An apparatus for transmitting quadrature modulated signals comprising:
 - means for quadrature modulating first and second signals on a first subcarrier,
 - means for quadrature modulating third and fourth signals onto a second subcarrier,
 - means for quadrature modulating said first and second subcarriers onto a carrier, and
 - means for transmitting said quadrature modulated carrier.
 9. An apparatus for transmitting quadrature modulated signals comprising:
 - means for quadrature modulating first and second signals on a first subcarrier,
 - means for quadrature modulating third and fourth signals onto a second subcarrier,
 - means for summing a sync signal with one of said subcarriers,
 - means for quadrature modulating said first and second subcarriers onto a carrier, and
 - means for transmitting said quadrature modulated carrier.
 10. An apparatus as defined in claim 9, in which a processor means is used for quadrature modulating said first and second signals and said third and fourth signals.
 11. An apparatus as defined in claim 10, in which said processor means includes a memory means containing a prototype pulse having a subcarrier component, and said first and second subcarriers produced by summing prototype pulses in said microprocessor means.

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